AD-A117 648 ROYAL NAVAL PERSONNEL RESEARCH COMMITTEE LONDON (ENGLAND) F/G 6/18
A TRIMIX SATURATION DIVE TO 660 METRES: STUDIES OF COGNITIVE PE--ETC(U)
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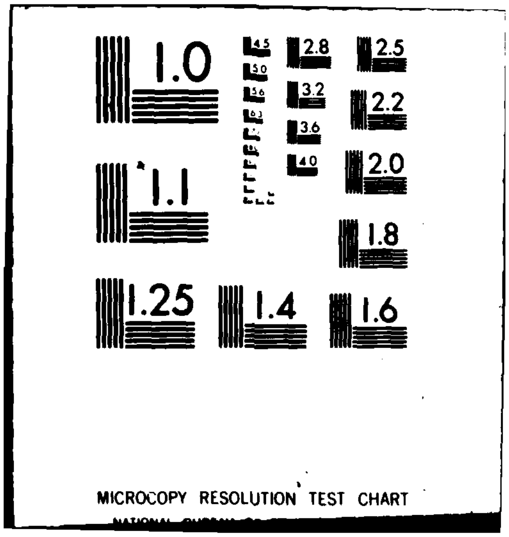
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MICROCOPY RESOLUTION TEST CHART

ABSTRACT

This paper reports psychological observations on men during a simulated (pressure chamber) dive to 660 msw using a gas mixture known as Trimix (He-O_2-N_2). Recent studies ~~by Bennett~~ (personal communication) have suggested that this mixture allows for faster compression with less impairment in performance than the mixture traditionally used (He-O_2).

Data were obtained from two divers on tests of cognitive performance, namely arithmetic ability, grammatical reasoning, perceptual speed, visuo-spatial manipulation and semantic processing.

At maximum depth there was a severe blanket impairment of ability to perform any of the tests. However at shallower depths, the impairments were not as marked, with performance at 300 msw close to that measured at surface pressure.

Subjects were also required to fill in two questionnaires, one concerned with the quality of their previous night's sleep, the other with their mood at the time. Sleep quality was disrupted throughout the 'dive', with one subject affected rather more than the other. Mood patterns varied less systematically, with large individual differences.

Low correlations between sleep quality and performance indicate that performance decrements were due almost entirely to breathing Trimix at high pressure.

CONTENTS

INTRODUCTION

1. The ability of an air breathing terrestrial like ourselves to dive to depths very much greater than 200 msw (metres of sea water), is limited by the extent to which compression to such depths can occur without loss of performance efficiency resulting in danger to the individual. To reach this depth the diver must breathe gases at a pressure equal to that of the surrounding water if he is to survive. Traditionally, the gases used have been a mixture of oxygen and helium, since pure oxygen produces convulsions beyond about 18 metres, while the nitrogen in compressed air produces narcosis (resembling drunkenness) with impairment of performance at depths greater than 30 to 40 msw (Shilling, Werts and Schandelmeier, 1976).

Unfortunately, although helium at atmospheric pressure is considered to be one of the inert gases, rapid compression to 200 msw or more causes dizziness, vomiting and tremors with a general severe performance decrement. This last condition, known as High Pressure Nervous Syndrome (HPNS) requires compression times to 200 msw of 12 hours or more, with greater depths of 400 msw or 500 msw requiring several days of compression.

2. A variety of performance tasks have been used to measure the effects of oxy-helium at high pressure, the majority being carried out in a dry pressure chamber rather than open sea conditions. Baddeley (1966) has shown differences in manual dexterity between pressure chamber and open sea testing, suggesting that if performance decrements appear in a pressure chamber, it is unlikely that performance will be any better in open sea conditions. Pressure chamber testing ensures that any effects obtained are due to breathing a given gas mixture at high pressure rather than the many other factors present such as cold, poor visibility, or partial weightlessness.

With relatively slow rates of compression, the incidence of HPNS is low; however evidence for the effect of 'depth' on cognitive performance is equivocal. Biersner and Cameron (1970) found no difference between a surface control group and an experimental group (five subjects in each) on a cognitive figures test, a cognitive interference test and associative memory. O'Reilly (1974) reported decrements as a function of task complexity, with six subjects at 135 msw. In a further study O'Reilly (1977) found increased errors in arithmetic and longer reaction times at 160 msw. However, these effects lessened over time and he found no effect on other tests such as spatial orientation or associative memory. In contrast, Hamilton (1976) tested subjects in both oxy-helium and neon-oxygen mixtures at pressures up to 360 msw and found little or no effect on reaction time, manual dexterity, arithmetic ability, strength or time estimation.

At greater depths, Lemaire and Murphy (1976) reported impairment at 610 msw on visual choice reaction time and number ordination. Also Carter (1979) obtained detrimental effects in perceptual speed and number facility at 527 msw. Paradoxically, he also found an improvement in associative memory at depth.

More recently, Lewis and Baddeley (1981) obtained performance decrements on tests of short-term memory, arithmetic ability, perceptual speed, spatial manipulation and semantic processing in 'dives' involving seven subjects over five dives to simulated depths between 300 msw and 540 msw. They found no effect on grammatical reasoning and associative memory. However with this last test subjects made very few errors, and the task may have been simply too easy for the subjects. This may have disguised an improvement at depth as obtained in the Carter (1979) study.

Self-assessed mood and sleep quality have also been measured. Townsend and Hall (1978)

reported an increase in fatigue, mood disturbance and sleep loss in a 14 day open sea dive to 260 msw. Lewis and Baddeley (1981) also found mood disturbance and sleep loss throughout their five simulated dives. However, the low correlations between the subjective ratings of mood and sleep quality, and their various performance measures, suggest that these could not account for the performance decrements obtained.

3. Performance impairment up to 300 msw seems therefore to be fairly small, with an increase in general impairment beyond this depth. However, the major problem for commercial diving even to depths of 200 msw to 300 msw has been the time required for compression with an oxy-helium mix. One method of avoiding HPNS with rapid compression has been studied recently with some measure of success. This involves the introduction of a small amount of nitrogen into the gas mixture. Bennett (personal communication) and others have carried out a series of experiments with simulated pressure chamber dives both on animals and humans at pressures up to 600 msw using a helium, oxygen, nitrogen mixture known as Trimix ($He-O_2-N_2$). He reports faster compression rates with much less evidence of HPNS and suggests that the narcotic effect of the nitrogen counteracts the effects of helium at high pressure. One experiment with human divers involved compression to 460 msw in 12 hrs 20 mins with 5% nitrogen in an oxy-helium mix. Subjects spent four days at this depth. On day one there was a substantial decrement in performance, together with HPNS. These effects subsided by day two, although performance was still not at pre-dive levels. Performance returned to normal only after decompression to 300 msw. This however represents much faster compression times than can be safely achieved by conventional $He-O_2$ even with the one day 'stabilising' period.

4. The present dive was an attempt to examine further the effects of Trimix on deep 'dives' in a pressure chamber. Since nitrogen is assumed to counteract the effects of HPNS, the presence of this syndrome would indicate that a higher proportion of nitrogen is required. Thus, given that HPNS did appear in the Bennett study, the present dive increased the amount of nitrogen to 10% of the gas mixture in an attempt to improve the therapeutic effect.

The dive reported forms part of a continuing project on simulated deep diving being carried out at the Admiralty Marine Technology Establishment Physiological Laboratory (AMTE/PL). Other than the measures reported, the dive also included a study of effects on the nervous system, haematology, respiratory physiology, metabolism and biochemistry. Reports of previous dives in the same project can be found in Lewis and Baddeley (1981), Hempleman et al (1978) and Hempleman et al (1980). The present dive was numbered 12B for cross reference with other sources.

The results of only one dive with two subjects are reported. There are several reasons for this. Firstly, if Trimix proves to be as efficient as its supporters claim, the implications are fairly far-reaching and this may give priority to further development with the novel mixture. If however, the claims for its efficacy are somewhat optimistic this may suggest that serious consideration should be given to whether the cost of further research using Trimix justifies limited usefulness. (The current cost of such research runs to about £100,000 per dive.)

Secondly, the present study involves testing at a number of points throughout the dive, allowing for a mapping of cognitive performance over time. This generated considerably more data than previous dives. Lewis and Baddeley (1981) tested on one occasion during the dive, at maximum depth, to compare against pre-dive performance and performance just prior to reaching surface pressure.

METHOD

Sleep and Mood Questionnaires

5. These followed the form and procedure of Lewis and Baddeley (1981). Upon awakening each morning, subjects were asked to fill in two brief questionnaires. One was concerned with the quality of their previous night's sleep, the other with aspects of their mood at the time. Both questionnaires were to be completed each morning from ten days before commencing the dive, to establish a 'surface baseline', throughout the dive and for nine days after the dive to investigate whether the patterns had returned to those of pre-dive testing.

6. The sleep questionnaire consisted of a number of questions enquiring as to general sleep quality, dreams recalled and number of times the subject woke up during the night; one item required the subject to make a perpendicular mark across a 10 cm line, the two ends of which were labelled 'worst possible' and 'best possible' (sleep), indicating his subjective assessment of the quality of the previous night's sleep.

7. The mood questionnaire consisted of 18 bipolar adjectives describing different aspects of mood, eg Alert-Drowsy, Happy-Sad, each member of a pair being at either end of a 10 cm line. The subject was again required to make a perpendicular mark on the line indicating how he felt on that particular dimension at the time of filling in the questionnaire. This "Visual Analogue Scale" (VAS) for measuring mood was derived from Norris (1971) and was used in this form by Lewis and Baddeley (1981).

Cognitive Performance Testing

8. Psychological performance was examined with a battery of six tests, given in the order below on each testing session. These were adding, grammatical reasoning, visual search for repeated letters, a visuo-spatial orientation task, judging number similarities, and semantic processing. The tests involved were a sample from a larger battery used in earlier dives, allowing between-dive performance comparisons. A smaller battery of tests has two main advantages.

a. It allows for more frequent testing at points throughout the dive . Previous studies in this series (Lewis and Baddeley, 1981) have compared pre-and post-dive surface performance with a single testing session of two hours at maximum depth. Testing at a number of stages in the dive gives a clearer picture of the general profile of performance particularly when superimposed on the profile of compression and decompression rates.

b. Again, in the previous dives, several of the tests involved measuring broadly similar cognitive abilities and were thus somewhat redundant.

9. Testing at a number of points during the dive does give rise to one complication. Since one is testing the same subjects on a number of different occasions with the same test material, the possibility arises that performance will improve simply because of increased amounts of practice on each session. This allows for development of more efficient strategies for tackling each task with testing on earlier sessions acting as practice for later sessions. The subjects could as a result get better regardless of the imposed stress or relief from stress to which they are exposed. In the case of compression, the effect expected is a decrease in performance as simulated depth is increased. Practice would work against such an effect and so any performance deficit is likely to be a genuine one,

probably due to the imposed stress. On relieving the stress (decompression), improvement in performance is expected and it is then difficult to determine whether observed improvement is due to less stressful conditions or practice with the tasks. If, however, after conditions have returned to 'normal', performance is seen to be similar to that of pre-stress sessions, increase in performance during compression can most plausibly be attributed to relief from stress rather than practice. Since learning curves typically follow a negatively accelerated function, it is possible to minimise this problem by giving practice in 'work-up' sessions prior to the testing sessions proper; this was the procedure followed.

Test Battery

10. In detail the tests used were as follows:

a. Adding This test lasted 15 minutes, consisting of three consecutive five minute periods. The subject was presented with a sheet which contained 125 columns of five, two-digit, numbers arranged in five equal rows. The task involved adding up as many columns as possible in the 15-minute period, marking the answer sheet when five and ten minutes had elapsed. (Wilkinson and Stretton, 1971).

b. Grammatical Reasoning (A-B sentence checking). This was a verbal reasoning test in which the subject assessed the truth or falsity of sentences describing the order of a letter pair following the sentence. For example: A follows B - AB (false)
B is not preceded by A - BA (true)

The subject was required to check as many sentence-letter pair combinations as possible in two minutes (Baddeley, 1968).

c. Visual Search for Repeated Letters This test lasted two minutes during which time the subject was required to look through an array of randomly chosen letters and for each row cross out any consecutive occurrences of the same letter.

d. Manikin test This spatial ability test lasted five minutes. Here, the subject was presented with a series of stick figures representing a man holding a ball in each hand. The figure was either upright or upside down and facing towards or away from the subject. The figure held a different coloured ball (black or white) in each hand, and above each figure was a black or white ball. The subject was required to indicate whether the figure was holding the equivalent coloured ball in the right or left hand (Benson and Gedye, 1963).

e. Number Similarities This test which involved both processing speed and short-term memory lasted ten minutes. Here, the subject was given two columns of number sequences with each sequence comprising from five to nine digits. The task was to indicate whether or not the two sequences in each set were identical. Half the sets were identical while half had one digit that differed (Reilly and Cameron, 1978).

f. Semantic Processing This task measured the speed with which subjects could retrieve information from long-term memory. It involved the subject in deciding whether or not a short sentence was true of the real world, based on their own knowledge and experience. Half of the sentences were obviously true, for example: "Captain is a military title", and half were obviously false, for example: "Veal cutlets crawl on their bellies" (Collins and Quillian, 1969). Subjects were given five minutes to verify as many sentences as possible.

Procedure

11. In order to guard against substantial practice effects, fourteen days before commencing the dive, subjects were given the test battery twice, in one morning and one afternoon session. This also familiarised the divers with the order of tests and general procedure used in their administration. A total of three pre-dive 'surface' control sessions were carried out on the two days prior to the dive, one of which was in the compression chamber. During compression, there were five separate testing sessions including one at 660 metres, the 'deepest' point of the dive. This was followed by six testing sessions during decompression, three of which were at approximately the same depths as on compression. Finally there were two post-dive 'surface' controls respectively four days and nine days after the dive was completed. Both of these were carried out in the chamber. Details of timing and depth at which each testing session was carried out are given in Table 1.

On each occasion where the testing was done in the chamber, subjects were given the test materials just prior to the session (through an airlock during the dive) and administration of the testing was via microphone and headsets. Due to familiarity with the testing procedure, the subjects were merely reminded briefly of timing and basic instructions on each occasion.

With two of the sessions (See Table 1) it was possible only to have a shortened version of the test battery. In this event the subjects were given two minutes for each test, with all tests included in the same order as for other sessions.

RESULTS

Sleep Quality

12. For the purposes of this analysis, the measure used in reporting results is the subjective rating of sleep quality on the Visual Analogue Scale in the questionnaire.

Figure 1 shows the profile of subjectively rated sleep quality. There were several days when subjects did not fill in the questionnaires and these were , unfortunately, the days on which the dive was at its deepest level. As other measures will show, throughout this period, the abilities of both subjects to carry out even very simple tasks were severely impaired. The missing data is thus an indicant of fairly substantial impairment of mental function.

From the data that are available, a pattern similar to that of previous dives emerges, with a sudden impairment in sleep quality at the start of the dive for both subjects. With subject MG (Figure 1a), adaptation to chamber conditions did not appear until near the end of the dive. There was a single night of good sleep at day 14 (450msw). Subject MSE (Figure 1b) showed a more gradual impairment throughout compression with fairly fast adaptation after onset of decompression. It is clear however that even with this subject, sleep quality did not reach pre-dive levels until close to the end of the dive. This was also true for subject MG, around day 34 (140 msw).

Comparisons of these data with other measures used will be made after reporting the remaining results on mood and cognitive performance.

Table 1. Testing Schedule

(Dive commenced at 10.00 on Day 1)

TESTING SESSION	DAY	TIME (APPROX)	LOCATION	DEPTH	DURATION
1	-2	1400	CHAMBER	SURFACE	FULL
2	-1	1100	OFFICE	SURFACE	FULL
3	-1	1500	OFFICE	SURFACE	FULL
4	1	1300	CHAMBER	300 msw	ABRIDGED
5	1	2100	CHAMBER	420 msw	ABRIDGED
6	2	1800	"	420 msw	FULL
7	3	2000	"	540 msw	"
8	5	1000	"	660 msw	"
9	11	1000	"	538.5msw	"
10	16	1000	"	418 msw	"
11	21	1200	"	294.5 msw	"
12	32	1200	"	145 msw	"
13	40	1700	"	12 msw	"
14	41	1100	"	2 msw	"
15	45	1200	"	SURFACE	"
16	50	1500	"	SURFACE	"

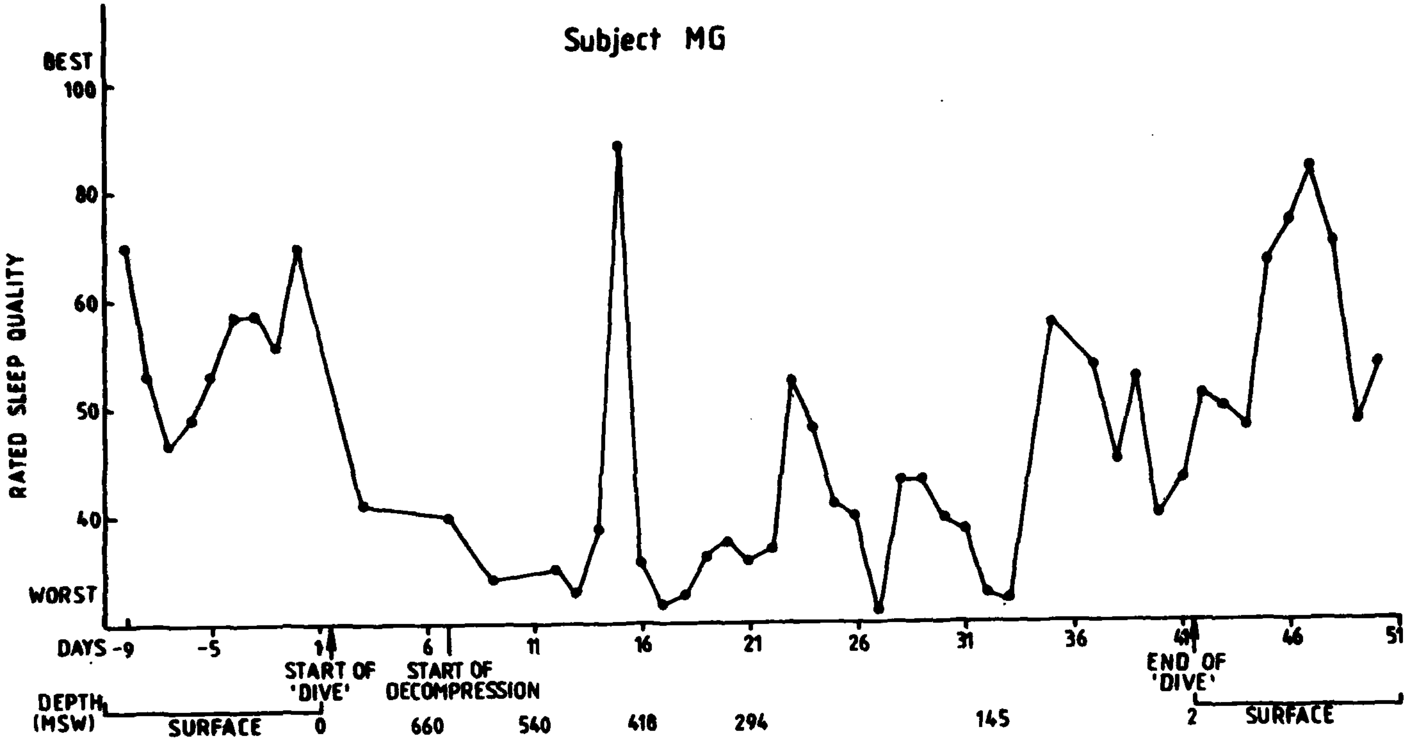
Subject MG
BEST
100
80
60
50
40
WORST
RATED SLEEP QUALITY
DAYS -9
-5
1
6
11
16
21
26
31
36
41
46
51
START OF 'DIVE'
START OF DECOMPRESSION
END OF 'DIVE'
DEPTH (MSW)
SURFACE
0
660
540
418
294
145
2
SURFACE

Figure 1a

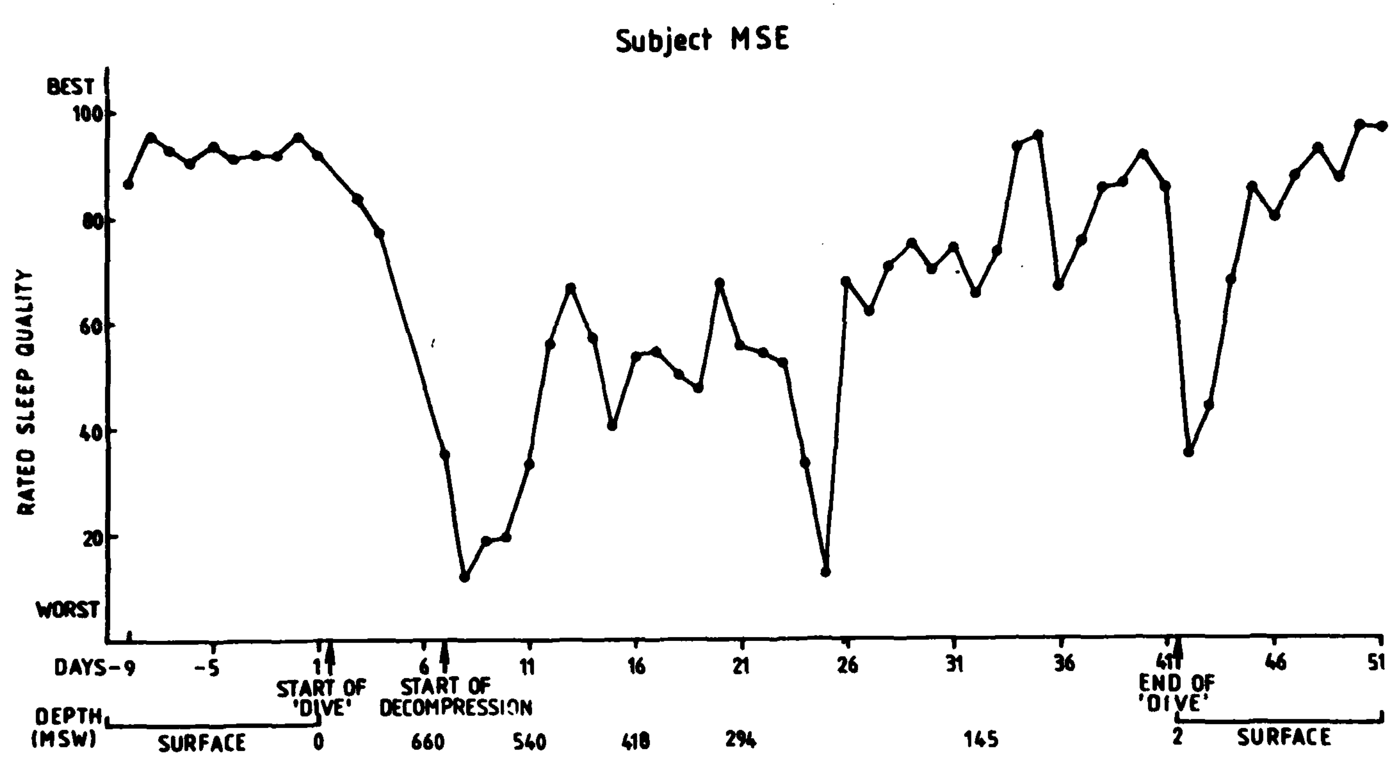
Subject MSE
BEST
100
80
60
40
20
WORST
RATED SLEEP QUALITY
DAYS -9
-5
1
6
11
16
21
26
31
36
41
46
51
START OF 'DIVE'
START OF DECOMPRESSION
END OF 'DIVE'
DEPTH (MSW)
SURFACE
0
660
540
418
294
145
2
SURFACE

Figure 1b

Mood Ratings

13. From the mood rating data, two scores were computed for each questionnaire giving a measure of 'alertness' and of 'tranquility' by combining the various ratings, weighted as suggested by Herbert, Johns and Dore (1976).

Of the scores obtained, only MG's 'alertness' level clearly changes in a systematic fashion with a substantial drop in 'alertness' at the deepest stages of the dive. Recovery to pre-dive levels occurs about half-way through the decompression phase (about 150 msw) to a fairly stable level for the rest of the dive.

The level of 'alertness' for MSE and of 'tranquility' for both subjects followed a rather less systematic pattern, showing no clear changes with depth. There are three possible reasons for this. The aspects of mood may have been largely unaffected by breathing Trimix at high pressure, or responses were being made which did not truly reflect mood state at the time, or the weightings used in calculating 'alertness' and 'tranquility' were not entirely appropriate.

In view of these problems, the derived measures should be treated with caution and further analysis and discussion of the mood rating data will be kept to a minimum.

Performance Testing

14. Results for each test are shown in Figures 2 to 7. With data from just two subjects, statistical analysis is somewhat inappropriate. Results will therefore be reported in the form of raw scores and general observations. Data given in the figures are number completed correctly on each testing session before, during and after the dive. Percent error scores for each test across sessions are given in Tables 2a and 2b.

15. Before examining the scores in detail, it is worth considering omissions from the reported data. It was not possible to collect data on two occasions during the dive. These both involved subject MSE shortly after reaching 420 msw on compression. A small amount of data was available from subject MG on the same occasion. At this testing session, MSE was unconscious and MG found great difficulty concentrating on the instructions given. Both subjects were able to attempt all of the tasks at this depth 21 hours later, and also at this depth during decompression.

At 660 msw, neither subject was able to produce much data. Both were conscious, but incoherent, subject to outbursts of laughter and could not concentrate long enough to find the correct test.

The data from these occasions could only be considered as genuinely missing had the subjects refused to do the tests or if any had been omitted by the experimenter. Neither of these were the case, and since the study is concerned with the effects of Trimix at high pressure on cognitive performance, the inability of the subject to complete the tests is a major indication of these effects. On these occasions, scores of zero have been recorded.

One final point is that on the third pre-dive testing session, subject MG reported feeling very tired and lacking in motivation for the testing. For some of the tests, this has been clear from the performance data, giving a very low score. This should be borne in mind when comparing at-depth performance with pre-dive scores.

Table 2 (a). Performance testing error data (%) - Subject MG

TEST SET	DAY	DEPTH	ARITH.	A-B	VIS. SER.	MANIKIN	NUM. SIM.	SEM. PROC.
1	-2	S	5.8	12	21.4	1.7	3.7	0
2	-1	S	13.3	5	25.0	1.0	3.3	1.1
3	-1	S	21.2	0	31.4	1.6	3.3	0.7
4	1	300	25.0	31.3	30.2	2.4	2.3	8.0
5	1	420	100.0	45.5	28.6	5.7	11.5	10.5
6	2	420	37.1	0	14.6	2.1	5.5	0.8
7	3	540	70.0	0	46.7	0	-	7.1
8	5	660	100.0	-	81.0	6	-	25
9	11	539	100.0	66.7	79.6	3.8	12.0	7.7
10	16	418	53.3	11.1	27.9	1.4	4.6	2.0
11	21	295	25.0	0	30	0	5.6	2.9
12	32	145	13.0	0	6.5	0	6.5	1.3
13	40	12	7.1	0	10.4	0	2.5	2.4
14	41	2	11.6	0	32.4	0.45	2.8	0
15	45	S	10.9	0	42.2	0	0	5.8
16	50	S	3.8	8.3	30.6	0.45	2.7	0

S - At surface pressure

A dash indicates S was unable to do the task.

Table 2(b). Performance testing error data (%) - Subject MSE

TEST SET	DAY	DEPTH	ARITH.	A-B	VIS. SER.	MANIKIN	NUM. SIM.	SEM. PROC.
1	-2	S	12.8	20.8	3.8	1.7	5.4	0
2	-1	S	6.5	6.5	0	4.7	4.1	1.0
3	-1	S	8.6	8.3	0	3.2	2.7	1.5
4	1	300	30.8	20.0	17.6	2.4	14.3	0
5	1	420	-	-	-	-	-	-
6	2	420	37.0	0	11.8	20.7	3.4	0.8
7	3	540	65.2	50.0	28.6	26.6	17.2	29.2
8	5	660	-	-	-	-	-	-
9	11	539	34.2	0	23.1	7.8	6.4	9.4
10	16	418	18.8	8.3	12.9	2.0	4.4	0
11	21	295	6.8	0	0	0	4.7	0
12	32	145	6.25	0	2.9	0.56	2.13	1.1
13	40	12	6.3	2.5	9.7	0.96	0	1.6
14	41	2	4.8	2.3	8.6	0.57	6.1	1.0
15	45	S	10.8	0	12.1	1.8	1.9	1.0
16	50	S	9.0	5.4	4.3	0.52	2.1	0.45

S - At surface pressure

A dash indicates S was unable to perform the task.

16. <u>Adding</u> Figure 2 shows the number of sums completed correctly on each testing session. Despite a fairly large difference in baseline performance between subjects, the pattern was the same for both, with substantial impairment at depths greater than 300 msw. Improvement occurred on the second testing session at 420 msw, but performance was still below baseline for both subjects. Subject MSE recovered more rapidly, with performance back to normal at around 300 msw during decompression. This did not occur until around 150 msw with MG, but this difference can be set against the relatively higher baseline performance of MSE. Error data shows a similar pattern with a substantial increase in percent errors at depths of 420 msw and greater.

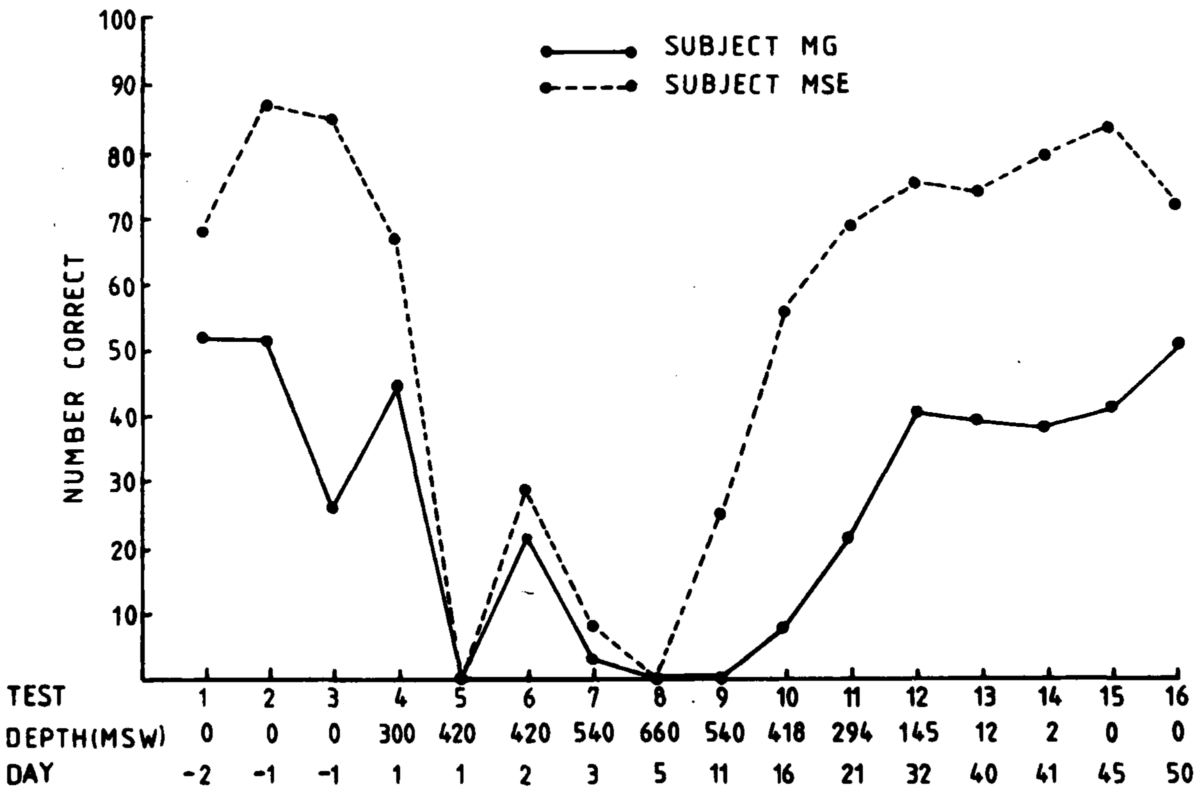

Figure 2

17. <u>Grammatical Reasoning</u> The scores on this test are shown in Figure 3. As with adding there was a substantial drop in performance at maximum depth (660 msw). Again performance was at zero for MSE at 420 msw on day 1. Performance was just less than baseline for both subjects at 300 msw, on compression. On decompression, MSE recovered rather more rapidly with performance back to pre-dive levels at about 300 msw, than MG who appeared to recover at about 150 msw. Again too, this may be set against a relatively low baseline of performance.

Percent errors appear to show little consistent effect of depth on this test.

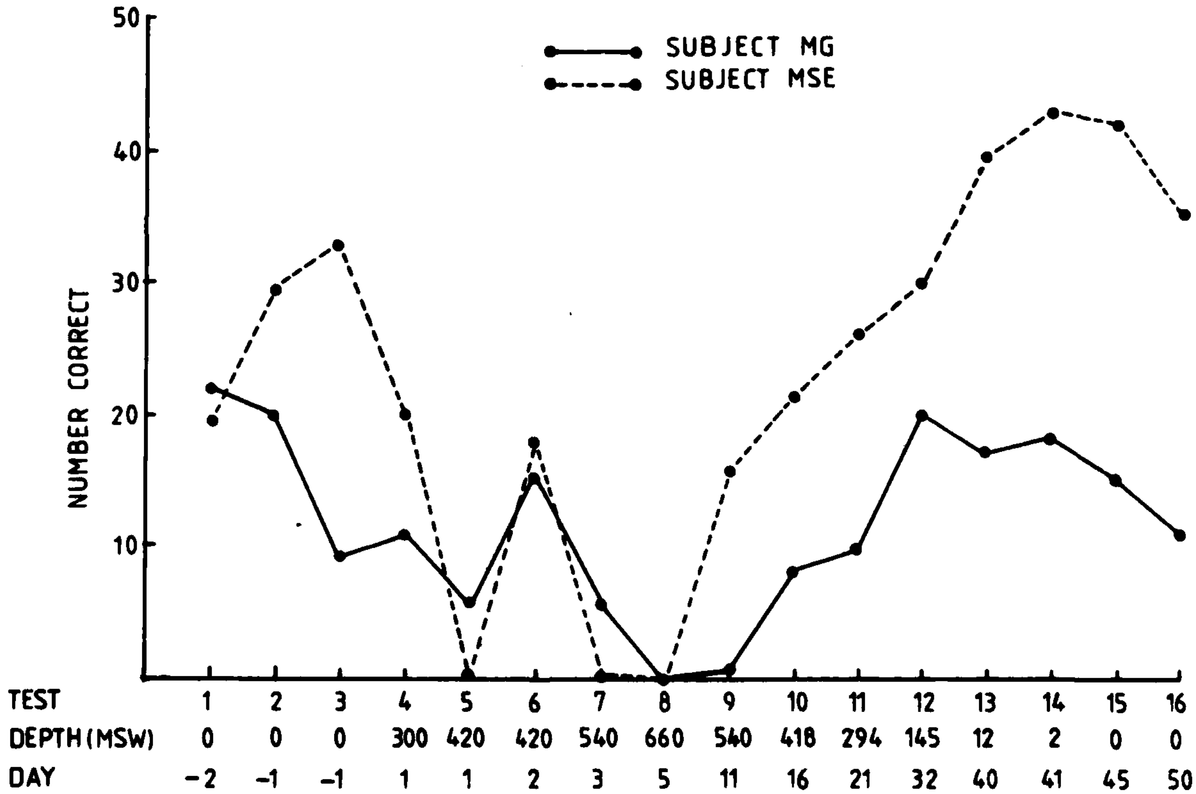

Figure 3

18. Visual Search Figure 4 shows the pattern of performance on this task. This test seems rather less sensitive to the effects of depth. Except at the maximum of 660 msw, and MSE on Day 1 at 420 msw, performance could not be considered any different from surface baseline. It is interesting that although MG was affected at 420 msw on Day 2 for adding and reasoning, he showed no decrement in visual search performance, compared with pre- and post-dive surface testing.

Error rate was high at 540 msw for both subjects on compression and decompression, and also at 660 msw for MG (MSE could not attempt this test at 660 msw); errors otherwise showed a rather erratic pattern.

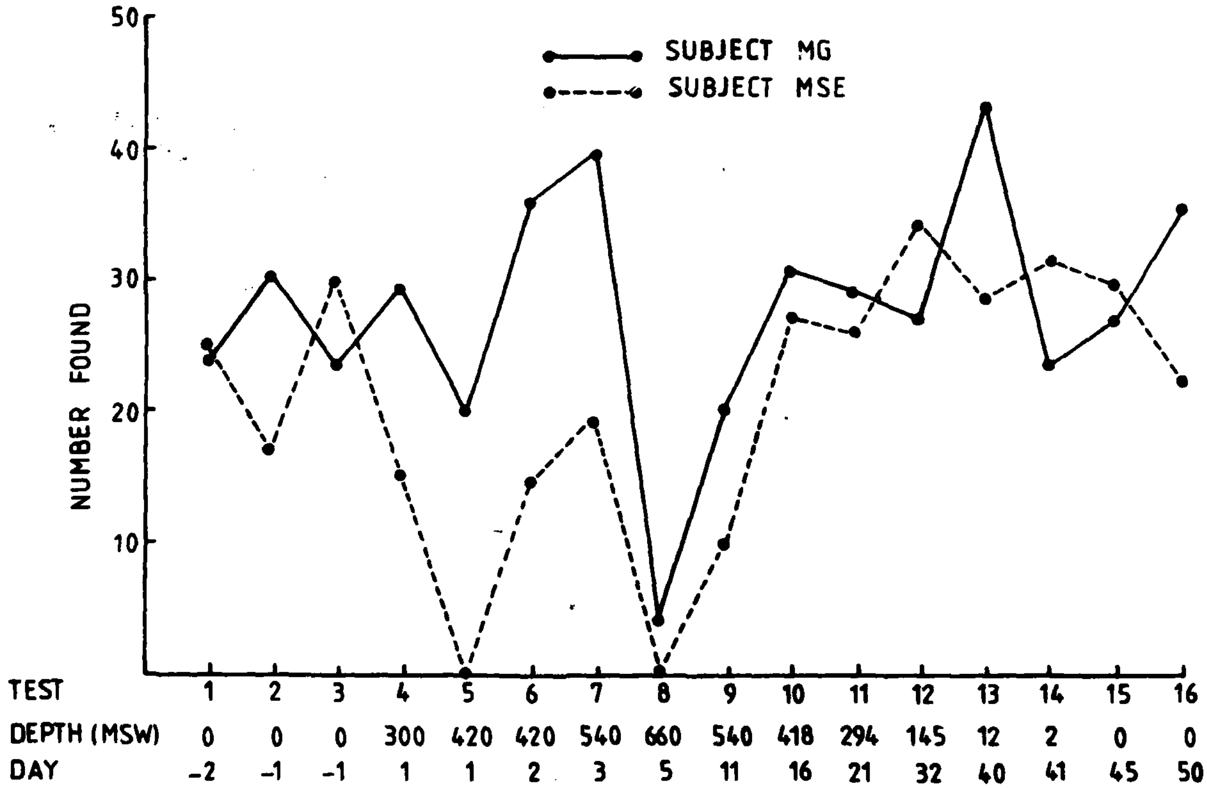

Figure 4

19. Manikin The results of this test are shown in Figure 5. For subject MG, the pattern here is similar to that for visual search with a substantial drop at 660 msw and a decrement at 540 msw on decompression. Otherwise performance was relatively unimpaired.

For MSE the decrement was over a longer period with the initial drop at 420 msw, followed by partial recovery at the same depth a day later. Of interest here was the substantial increase in post-dive performance on this test for MSE during decompression, at about 300 msw. This indicates a fairly substantial practice effect on the test. Error rate follows these results fairly closely although the overall error rate was very low, particularly for MG.

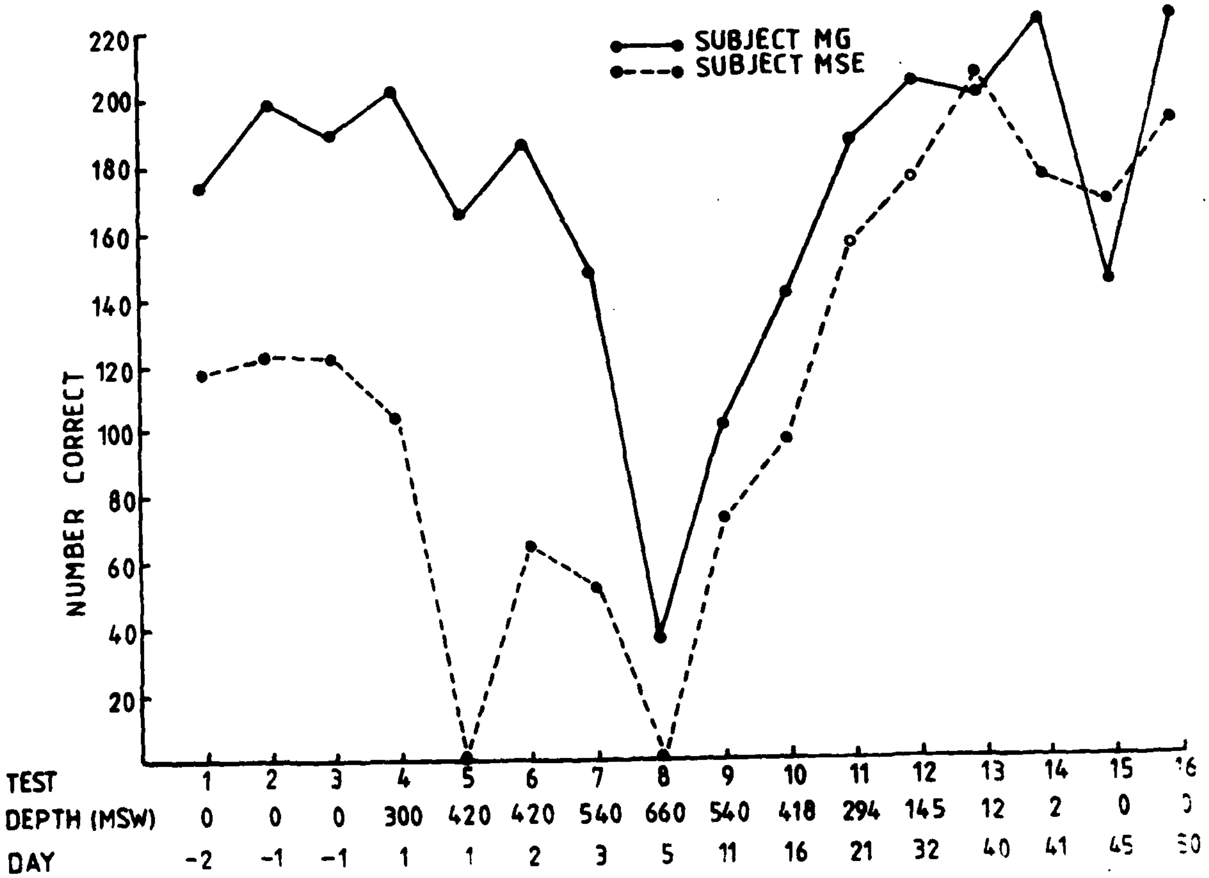

Figure 5

20. Number Similarities The results of this test are shown in Figure 6. As with the previous two tests substantial decrement appeared only at depths of 540 msw and greater for both subjects with smaller effects at 300 msw and 420 msw. Apart from the initial 420 msw drop for MSE, the two subjects' performance patterns were very similar for this test.

Errors were comparatively low at depths less than 540 msw.

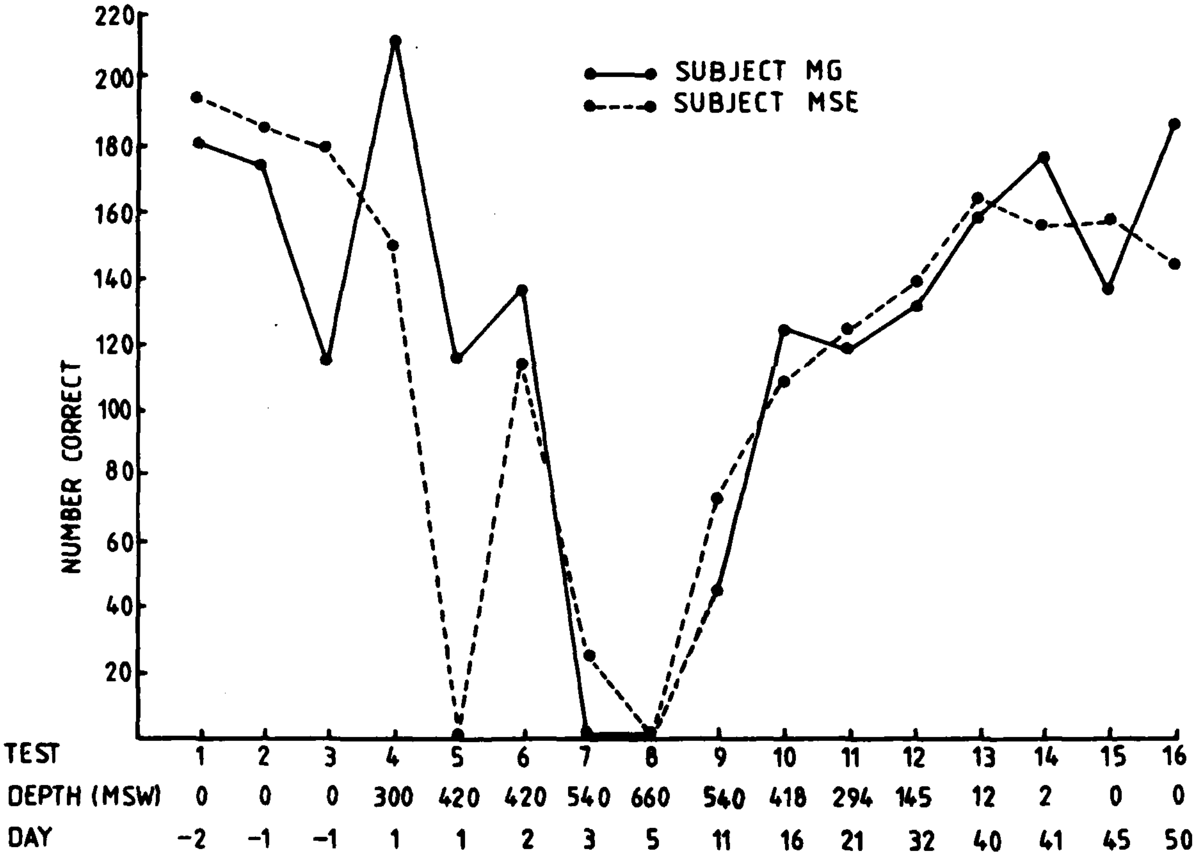

Figure 6

21. Semantic Processing Figure 7 contains the data for this test. On compression, the drop in performance occurred largely at 540 msw, again with smaller effects at 300 msw and 420 msw. Error rates were low except at 540 msw and 660 msw.

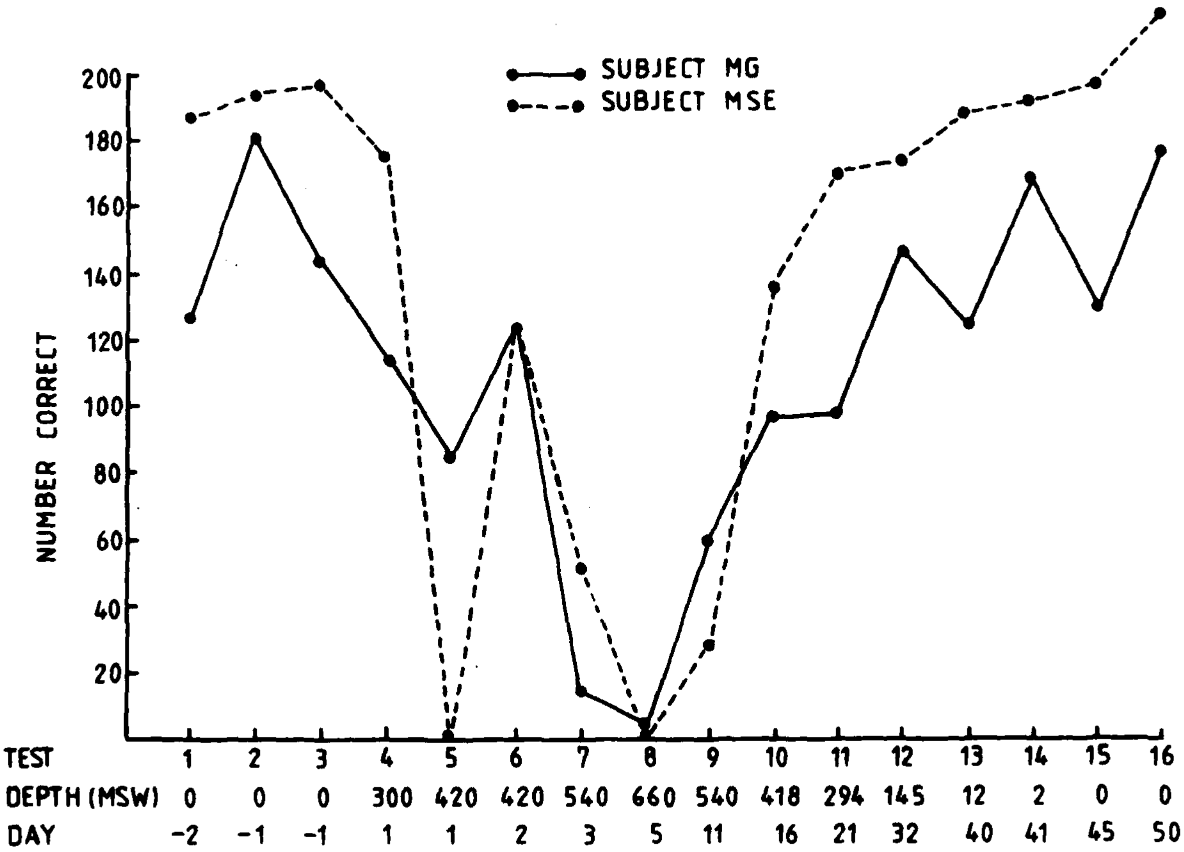

Figure 7

Correlations between Sleep, Mood and Performance

22. Pearson's 'r' was calculated between measures of sleep quality and mood, and between sleep quality and performance. Correlations between mood and performance were not calculated for three reasons. First, the measures of mood have been shown to be largely incoherent. Second, Lewis and Baddeley (1981) have shown that mood and performance are unrelated. Third, although sleep loss may affect performance tested later in the day, and tends to be a cumulative effect (eg Williams, Lubin and Goodnow, 1959), it is not clear that mood states as measured upon awakening are likely to affect performance measured later in the day.

The correlations computed indicated that for MG, sleep and alertness were related ($r = 0.642$). Other correlations between sleep and mood were not significant, nor were the correlations between rated sleep quality and performance scores on any of the tests.

DISCUSSION

23. The results presented indicate that there was a substantial blanket decrement in cognitive performance in divers breathing an helium-oxygen-nitrogen mix at 660 msw. This impairment was less marked at 540 msw, but still affected performance on all tests including grammatical reasoning. Lewis and Baddeley (1981) found this last test resistant to the effects of depth. Error rates on all tasks were also fairly high at 540 msw.

Testing at 420 msw, 21 hours after initial compression, demonstrated partial recovery when 'stable' at this depth. Performance on visual search was at or near surface baseline. However performance scores on all the remaining tasks were lower than at surface for both subjects. The effects were small in comparison to initial compression to 420 msw. Nonetheless, it suggests that this depth may be sufficient to produce reliable performance decrements with Trimix in addition to problems with compression rate. Performance at 300 msw was slightly affected on semantic processing, number similarities, grammatical reasoning and arithmetic. However visual search and manikin tests were largely unaffected at this depth.

The changes in rated sleep quality were fairly substantial throughout the dive, with MG affected rather more than MSE. The low correlations between sleep quality and performance measures, indicate that the impairments in cognitive performance cannot be attributed to sleep loss. Therefore performance decrements were presumably due to breathing an helium-oxygen-nitrogen mix at high pressure.

24. The impairment in performance observed in the present dive was substantially greater than that obtained in earlier oxy-helium dives in the same series (Lewis and Baddeley, 1981). The maximum depth reached in the present dive was also greater than those reached in the Lewis and Baddeley dives. However, it is still possible to compare performance between the two gas mixtures at the same depth, given that testing took place at various depths in the current dive. At 540 msw, the decrements with Trimix were far greater than those reported by Lewis and Baddeley (1981). This was also true for 420 msw, on initial compression to this depth. However when stable at 420 msw and at 300 msw, the comparison is less clear. Oxy-helium produced greater decrements on visual search, manikin and number similarity. Performance on grammatical reasoning was similar and largely unaffected in both mixes at these depths. Arithmetic ability was also similar with both mixes producing impairments on both 300 msw and 420 msw (stable). Semantic

processing was not tested at 300 msw in the earlier dives but showed similar impairments with the two mixes at 420 msw (stable).

The symptoms at 660 msw resembled those of nitrogen narcosis or drunkenness, and could perhaps be attributed to the amount of nitrogen chosen for the present dive. The 10% proportion is double that used by Bennett in his previous study. The Trimix theory suggested that since only a moderately beneficial effect was obtained using 5% nitrogen, increasing the proportion should increase the benefit.

25. More recently, Bennett and his colleagues have studied performance in Trimix with increasing proportions of nitrogen, (Bennett, person communication), again with some success. For the present dive it appears that the increase to 10% was too great for the maximum depth reached. However the solution of using $7\frac{1}{2}$% nitrogen is fairly simplistic. The symptoms on initial compression to 420 msw were those of HPNS despite inclusion of 10% nitrogen. However, with the pressure held at 420 msw, the symptoms of HPNS subsided within 24 hours. Even with this initial problem then, the overall compression rate to 660 msw was faster than rates used with oxy-helium. Compression to 660 msw was achieved in less than five days whereas Lewis and Baddeley (1981) report dives where compression to 300 msw was achieved in four days, 420 msw achieved in eight or nine days, and 540 msw reached in six days.

26. Preliminary reports from the other investigators (Hempleman, personal communication) suggest that although there are substantial physiological changes under these conditions, there is no immediate danger to the health of the divers. They were clearly able to survive at 660 msw. The important question then arises as to whether their cognitive abilities are sufficiently unimpaired for them to safely carry out the various tasks required of them upon reaching this depth. This was clearly not the case both for the speed at which the subjects worked through the tests and for the number of errors made and suggests that Trimix may not offer the neat solution to the HPNS-narcosis problem that at first seemed likely.

27. The major implications for divers working in open sea conditions are clear. Baddeley (1966) has shown that open sea performance may show substantially greater impairment at depth than would be predicted from performance in a pressure chamber. Given the dramatic effect on performance at both 540 msw and 660 msw, use of Trimix in open sea dives would be premature at present. This is particularly true in view of the error data since serious consequences may result from the diver being unaware of errors made. Speed of working would be less crucial in this respect. Further investigation, possibly varying the proportions of nitrogen according to depth may well prove the value of Trimix, if the finance is available for such costly research. On the basis of the present evidence however, the continued use of oxy-helium with lengthy compression times appears to be the best available method for cushioning the deep diver against fairly substantial impairments in his cognitive abilities.

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